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Combinatorial Measurement of Polymer Craze Growth and Fracture

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Craze Growth and Fracture in Thin Films

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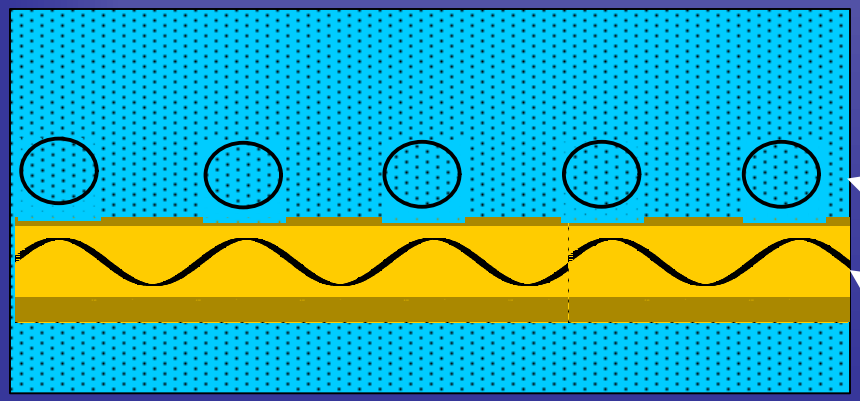
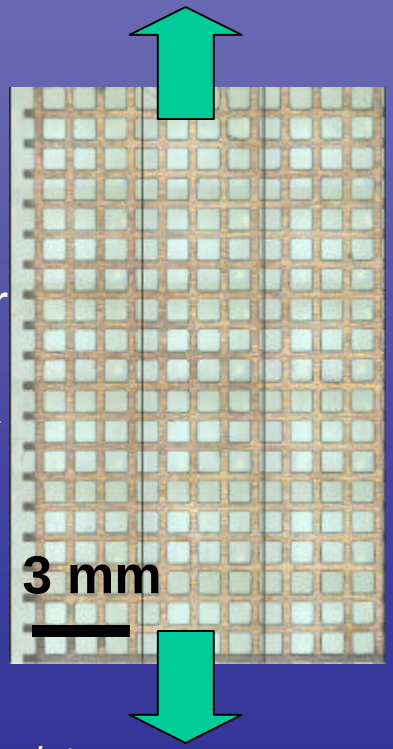
- Toughness of polymer related to craze formation
- Decades of research history on crazing
- Heterogeneities in processing of thin films may play role in craze formation and fracture properties



The Copper Grid Test

- Lauterwasser, B.D. and E.J. Kramer. “Microscopic mechanisms and mechanics of craze growth and fracture”, *Phil. Mag. A*, **39**, *4*, 469-495, 1979.

Copper Grid coated with glassy polymer



- Isolate crazes in thin films
- Statistical population of equally strained cells in one sample
- Copper plastically deforms to “lock-in” applied strain
- Use microscopy to analyze craze and fracture microstructures

Combinatorial Approach to Polymer Thin Films (gradients)

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Variables:

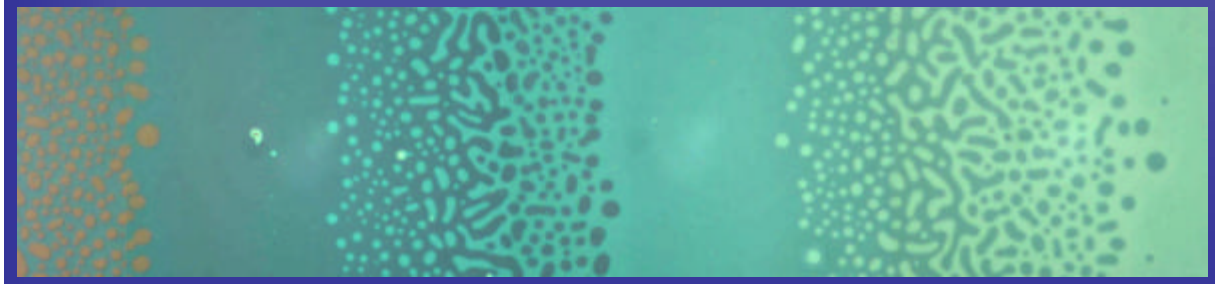
- Film thickness
- Crosslink density
- Chemical functionality
- Crystallinity
- Blend composition
- Surface Patterns

Properties:

- Confinement
- Surface energy
- Adhesion energy
- Toughness
- Biocompatibility
- Miscibility / Phase separation
- Wettability

Polystyrene →
H ~ 40 -120 nm

Poly(styrene-*b*-methyl methacrylate) →
H ~ 40 -120 nm



Poly(vinyl cinnamate)
H ~ 120 nm

UV →

Craze Growth in Semi-Crystalline Thin Films: ipS

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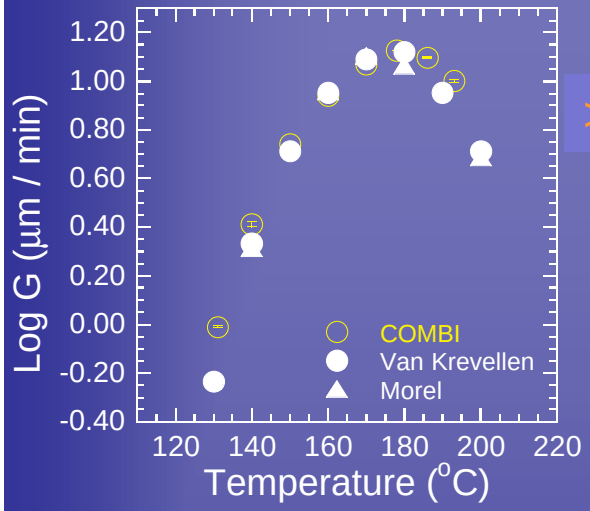
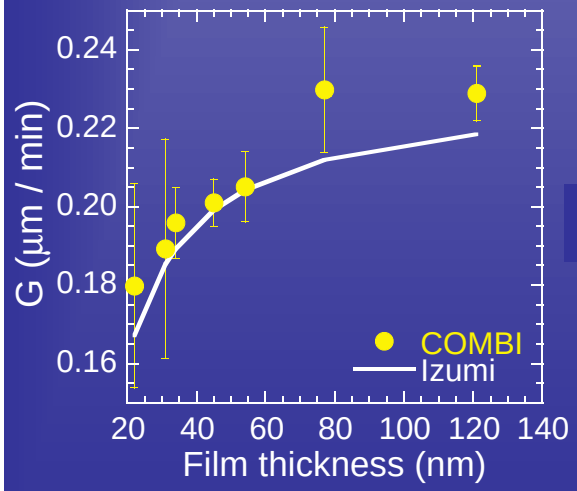
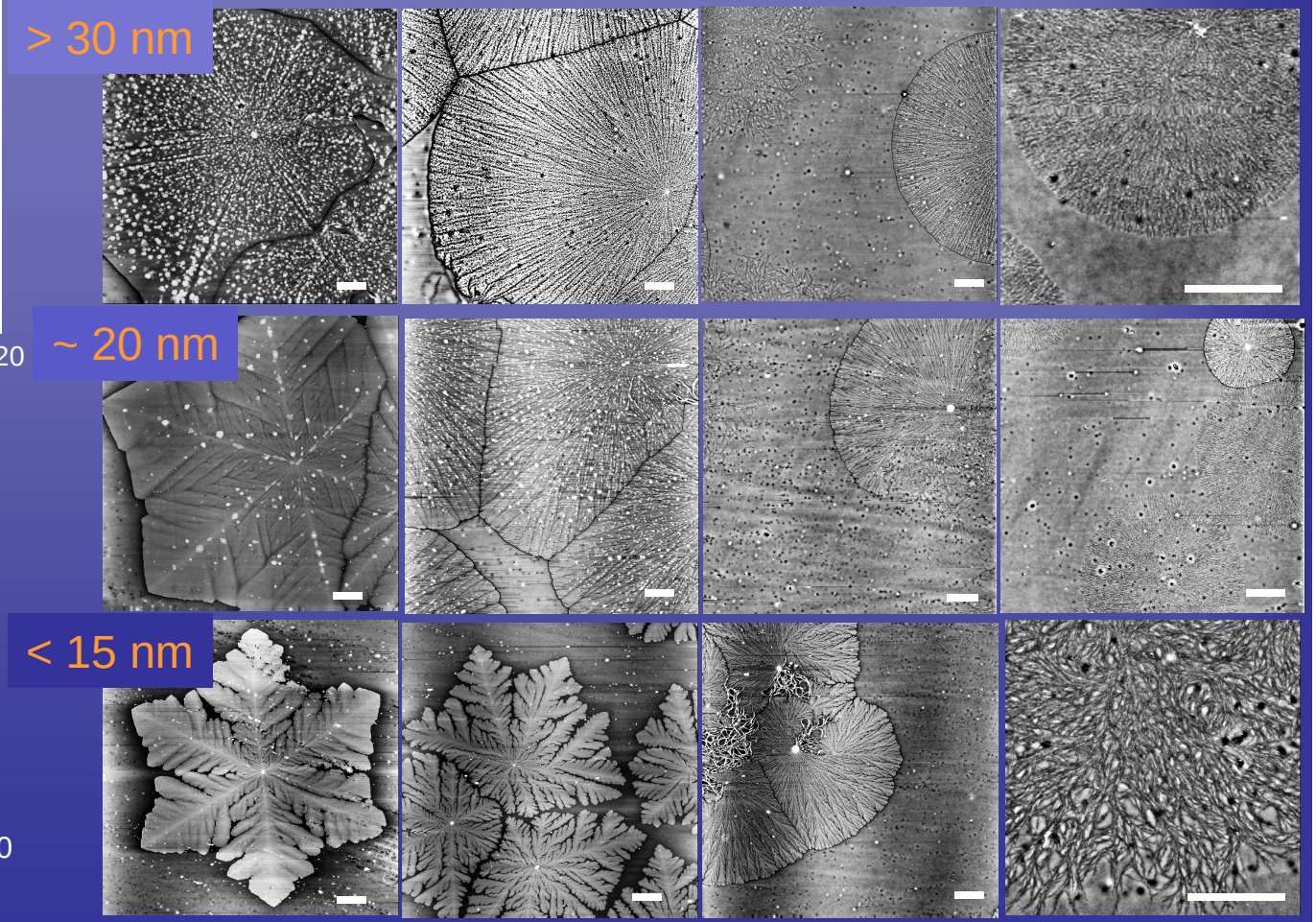
Gradients in film thickness and temperature lead to gradients in crystal structure and degree of crystallinity.







Scale bars: 10 μm

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Combinatorial Approach with the Copper Grid Experiment

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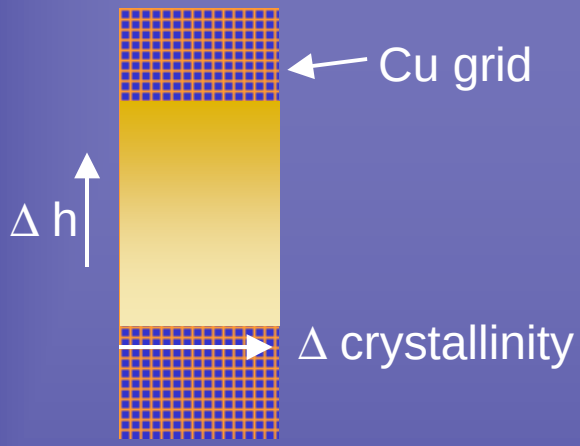
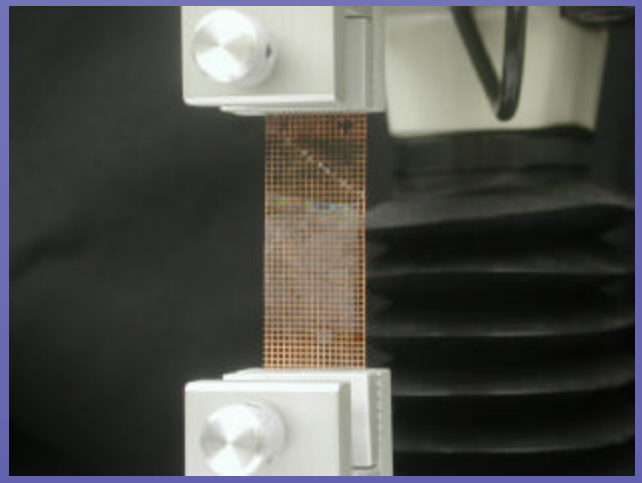
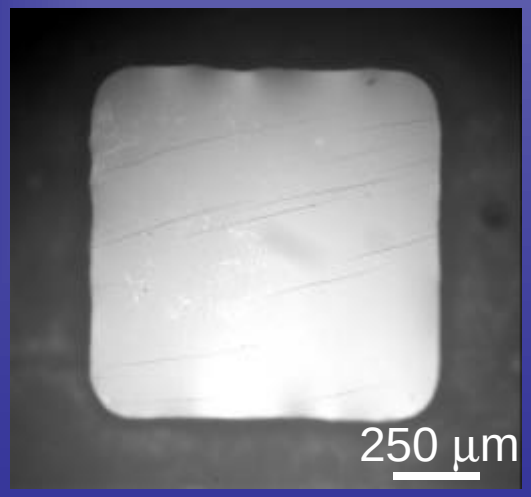
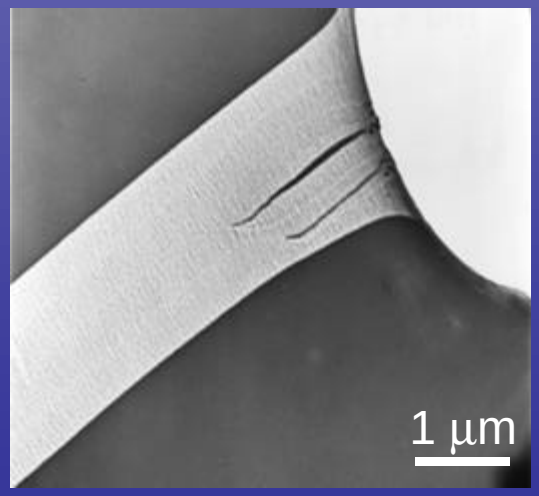




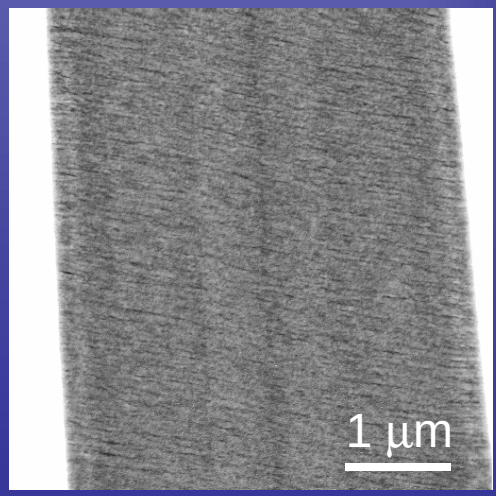
OM



TEM



AFM



AFM of Craze Tips

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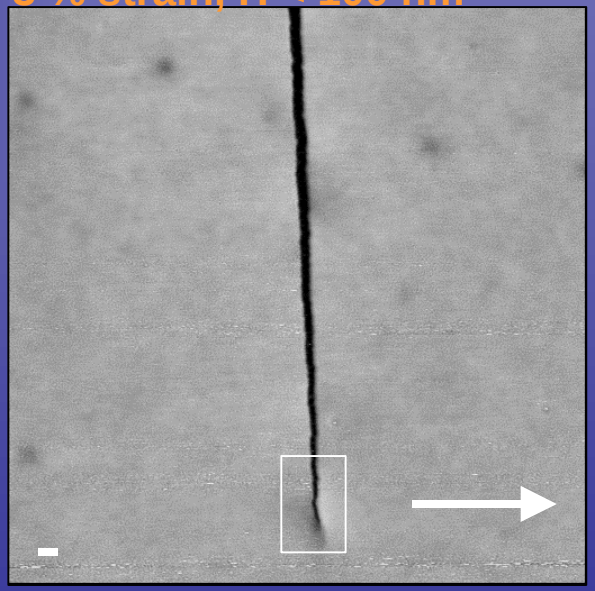
In the early stages of craze growth, little difference is observed between tip structure in films above and below 100 nm thick.

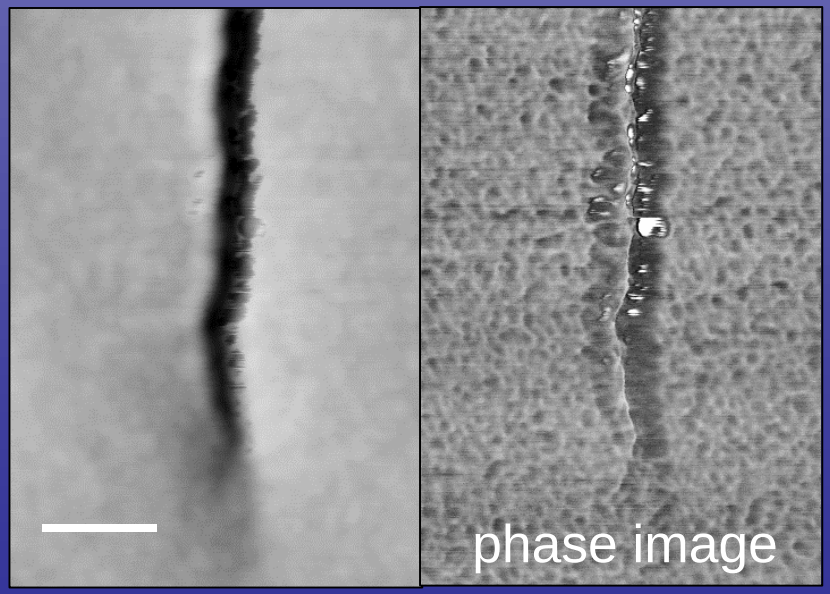
Tip images: always into amorphous film, never in contact with any other structures

Mid-Section Images: Far away from tip and any evidence of change in cross section size

3 % strain, H < 100 nm



Scale bars: 100 nm



AFM of Craze Mid-Section

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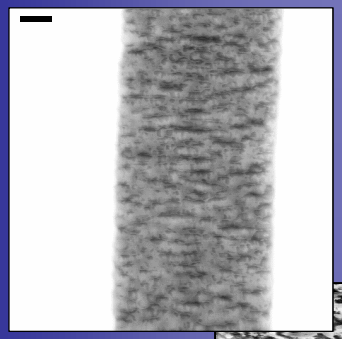
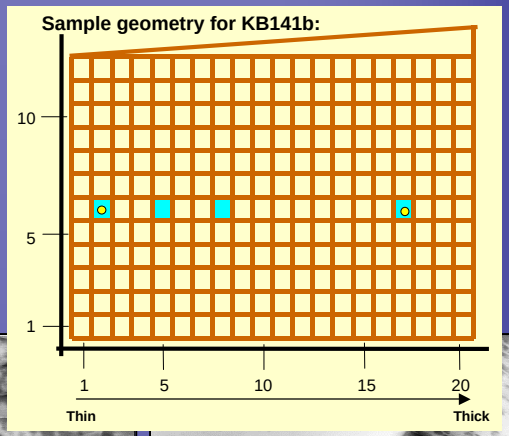
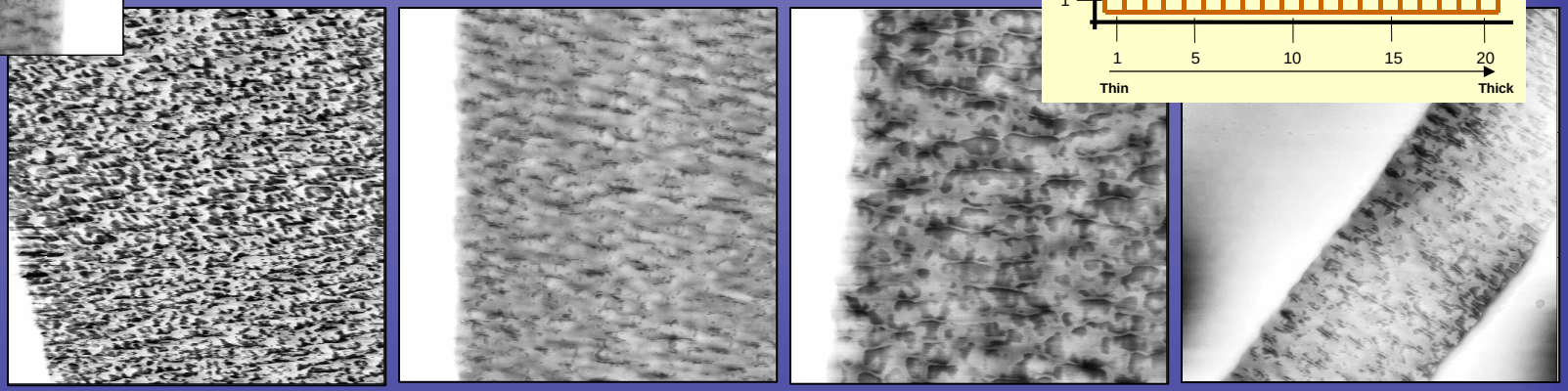


Scale bars: 100 nm

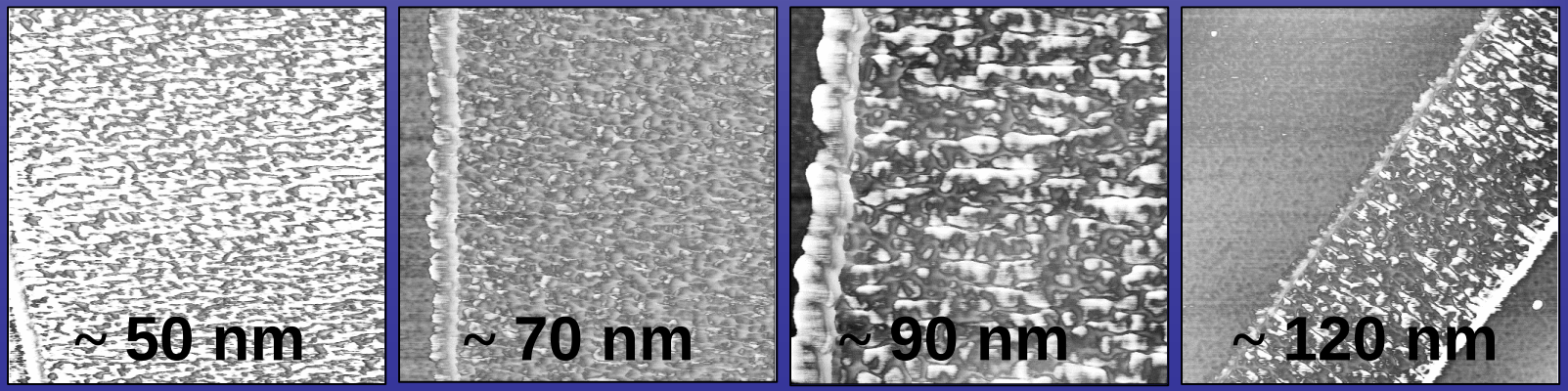
3 % strain



Height



Phase



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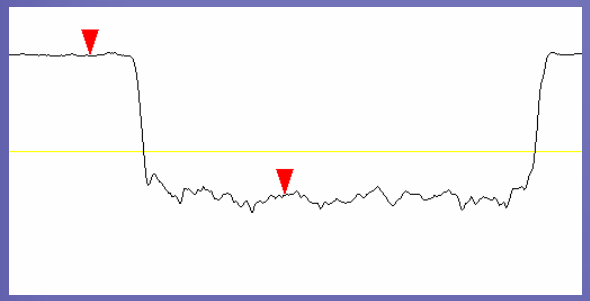
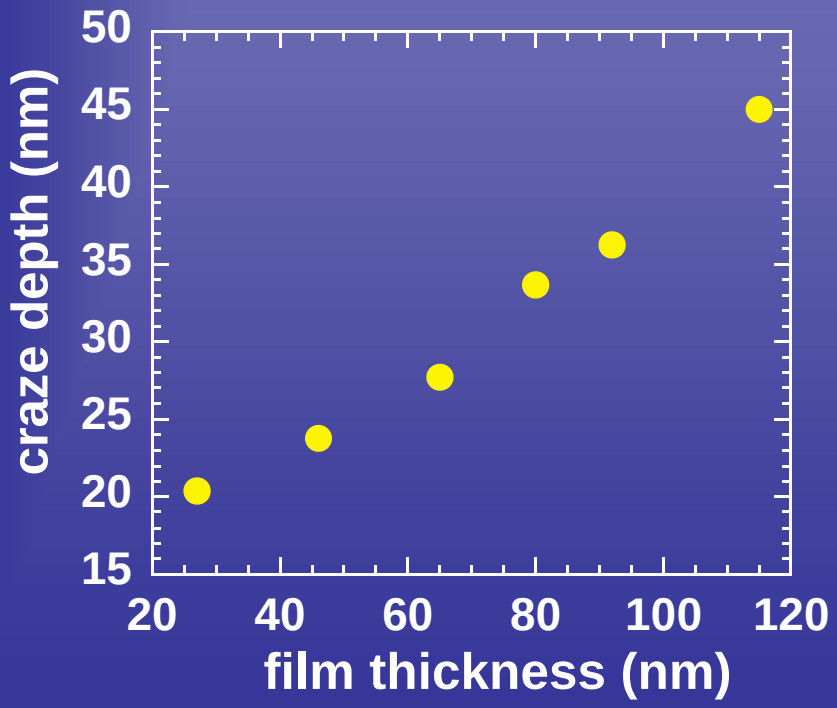
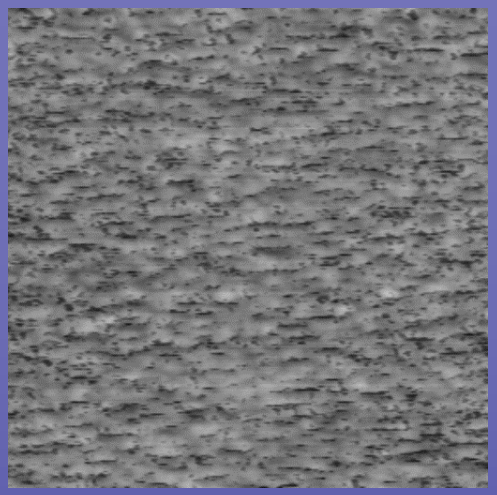
Craze Depth and Roughness

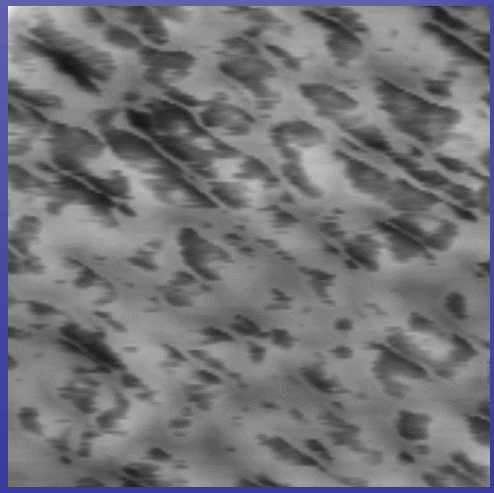






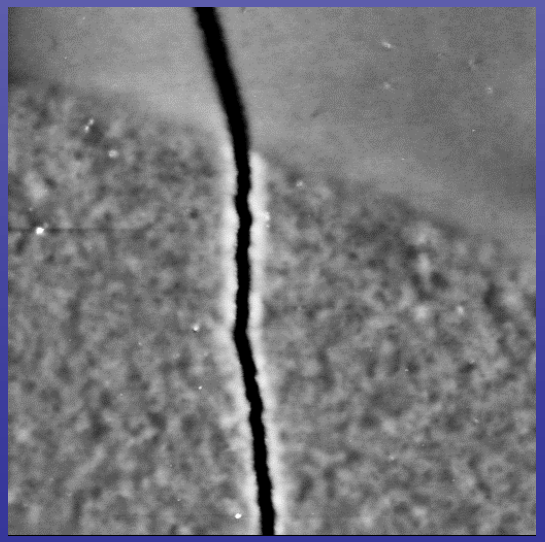
3 % strain
H ~ 50 nm

3 % strain
H ~ 100 nm



Conclusions / Future Plans

- Demonstrated applicability of the gradient combinatorial approach and AFM analysis to studying craze growth and fracture in thin films
- Future plans include pre- and post-strain crystallization (second gradient) as well as gradients in crosslink density, and other gradient variables



Acknowledgments:

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NRC ($$$)